Motivating Stroke Rehabilitation Through Music: A Feasibility Study Using Digital Musical Instruments in the Home

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ABSTRACT

Digital approaches to physical rehabilitation are becoming increasingly common [14] and embedding these new technologies within a musical framework may be particularly motivating [11,12]. The current feasibility study aimed to test if digital musical instruments (DMIs) could aid in the self-management of stroke rehabilitation in the home, focusing on seated forward reach movements of the upper limb. Participants (n=3), all at least 11 months post stroke, participated in 15 researcher-led music making sessions over a 5 week intervention period. The sessions involved them 'drumming' to the beat of self-chosen tunes using bespoke digital drum pads that were synced wirelessly to an iPad App and triggered percussion sounds as feedback. They were encouraged to continue these exercises when the researcher was not present. The results showed significant levels of self-management and significant increases in functional measures with some evidence for transfer into tasks of daily living.

Author Keywords

Stroke Rehabilitation; Digital Musical Interfaces; Auditory Feedback; Self-management; Entrainment

ACM Classification Keywords

J.3. Health; H.5.2. *Prototyping*; *User-centered design*

INTRODUCTION

Every year there are a reported 15 million strokes worldwide with 5 million survivors left with severe disability [23]. At a time when healthcare is under financial strain, the cost of stroke for the UK alone is estimated at 8.9 billion per year with treatment costing around 5% of UK NHS budgets [17]. Stroke survivors often receive little formal support to help with physical or psychosocial problems and are at considerable risk of incurring a secondary stroke [9].

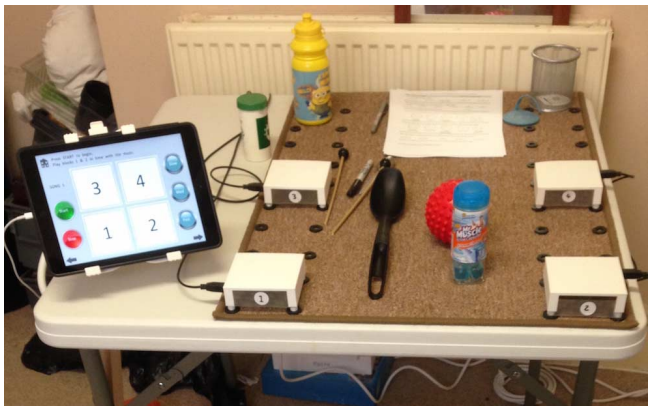

Figure 1: The study setup where P3 could sit at a table and perform active forward reaching activities using 4 bespoke digital drum pads synced wirelessly to an iPad App

The challenge, therefore, is to offer stroke survivors a motivating framework for initiating and repeating specific physical exercises, in the home environment. To maximize the exercise 'dose' (in line with animal literature suggesting that 400 – 600 repetitions are required for motor plasticity [13,15]) the framework should be intrinsically rewarding, a principle that has already been exploited by gamification approaches in HCI research [1,6].

Similarly, active music making could hold much potential for the self-management of stroke rehabilitation. Sports science has demonstrated that exercising to music results in a reduction in perceived effort for the same amount of work performed [10], which is likely to be partly attributable to the strong links between music and emotion [3].

The ability of music to motivate movement has already been exploited in a number of interventions for stroke survivors [20,22]. However, these studies have used

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traditional instruments such as electric pianos and drums [2,7,16,21] which tend to be costly and bulky and can rarely be tailored to the individual's needs and progress goals or implemented in the stroke-survivors home. In contrast, the use of specifically digital music technologies can constitute a low-cost and flexible approach that is well suited for the home environment.

Our previous exploratory research [12] using a series of focus groups revealed that stroke survivors reported high levels of motivation to use music as part of their rehabilitation. The dialogue led to the rapid prototyping of a number of digital musical instruments (DMIs) that were refined over a period of months in five musical workshops. Qualitative feedback and observations demonstrated that stroke survivors engaged with these devices and expressed a desire to use them within the home environment. However, none of the DMIs were suitable for individual use in the home as they required a workshop assistant to set them up and calibrate the system for each individual.

In the present study, we developed a new set of prototypes (bespoke digital drum pads) aimed specifically for self-management, and evaluated their acceptability for use in the home, as indicated by time on task and qualitative feedback. In addition, we took a number of health measures to determine how effective engagement with the devices would be for physical and psychological outcomes. The DMIs were designed with specific physical movements in mind after advice from stroke rehabilitation experts. The key research question for the study was: "Can DMIs help the self-management of upper limb rehabilitation in the home environment?".

METHOD

Designing For Stroke Survivors

The first phase of the study involved regular meetings with a neurologist and staff from a specialist upper limb stroke unit at the National Hospital of Neurology and Neurosurgery, London, who gave advice on physical movements most relevant to many stroke survivors. Additionally, we observed stroke survivors undertaking physiotherapy sessions on the ward over a period of months to gain insights into relevant design considerations.

The outcome from the dialogue and observations led us to focus on one simple, highly recommended movement: active seated forward reach. This involves keeping the elbow close to the body and reaching forward at table height. This exercise can improve upper limb strength in the shoulder, elbow and wrist, as well as improving balance [5]. It was also suggested to be an exercise that stroke survivors could perform without expert support on their own within the home. Key concerns expressed by health experts included cognitive ability to follow tasks and physical ability to perform them.

The second phase of the study involved designing and developing new prototypes that permitted active seated forward reaching exercises similar to those noted in the observations. The design involved building four digital drum pads spaced in a 2 x 2 configuration, with precise spacing calculated as a percentage of each patients maximal forward reach as recommended in prior consultations. Our design facilitated bimanual exercises that were actively encouraged by clinicians on the ward. Staff also stated that when undertaking forward reach exercises patients should look at their hand when they perform the tasks, so as to achieve as much feedback as possible, given the well known proprioceptive difficulties that stroke survivors experience [8].

After considering a number of ways in which to couple movements to music, we selected rhythmic entrainment to the beat of self-selected songs. There is a strong rationale for entraining to the beat of self selected songs as this facilitates a framework for rehabilitation[4], permitting hundreds of repetitions in a relatively short time frame. The protocol was implemented via a simple iPad App so as not to exclude patients with mild cognitive impairments, while the digital drum pads were designed to be low profile allowing for participants with relatively weak physical ability.

Study Design

A multiple case study design was used comprising three key phases (pre-intervention, intervention and post-intervention). The participants (n=3) were all individually assessed using single case analysis on 6 physical impairment measures taken at multiple time points over all phases.

The primary measure was an arms length reach test to assess how far the participant could reach their arms forward on a table from a seated position while keeping their body upright. The remaining 5 measured active range of movement (ROM) in the arm using standard physiotherapy techniques with a goniometer (a tool to measure degrees of active movement). The shoulders ROM was measured with participants actively reaching up as high as possible with a straight arm (flexion) and then by reaching back (extension) giving two measurements. One measurement of elbow flexion was achieved by bending the elbow and pulling the hand into the shoulder as far as possible and the final two measurements were wrist extension (lifting hand up) and wrist flexion (dropping hand down as far as possible).

A range of other physical and psychological measures were assessed pre and post intervention, along with daily diaries, questionnaires and a follow up semi-structured interview to probe the amount of time on task, level of enjoyment, engagement and fatigue in relation to the exercises, and possible transfer of effects to tasks of daily living.

Participants

P1 was a 50 year old male (27 months post stroke), P2 a 44 year old female (14 years post stroke) and P3 a 50 year old male (11 months post stroke). The suitability of all three for participation in the study was determined by an stroke

specific occupational therapist. Participants were not having any intensive physiotherapy sessions during the study, though attended local stroke support groups. All gave informed consent to participate.

Apparatus

Bespoke digital drum pads were produced by rapid prototyping with the aid of a number of Makerbot Replicator 2 Desktop 3D printers. After meetings with an occupational therapist to discuss sizes the digital drum pads were printed in plastic with a surface 10x10 cm and a depth of 3cm allowing space for a printed circuit board (PCB) to be mounted. The PCB board was designed and printed with the critical components required for each digital drum pad consisting of a piezo contact mic to trigger electrical signals sent via a BLE 113 low energy Bluetooth 4.0 breakout board wirelessly linked to a new purpose built iPad App. The iPad App was built using C++ within open frameworks iOS release v 0.8.4 and built within the Xcode 6.3 IDE. When designing the App the focus was on keeping it as simple and functional as possible bearing in mind potential cognitive difficulties from the users. White squares represented the 4 physical digital drum pads used for the intervention and were numbered logically replicating the physical placement of the blocks on a table directly in front of the participant (Figure 1). When a song played the white squares would flash green to give a visual cue dictating when the physical digital drum pads should be hit to help set up the entrainment to the musical beat. The digital drum pads were placed on rubber backed mats to prevent slipping. The 1x1cm feet of the digital drum pads sat into rubber washers that were stuck onto the mats at 10cm intervals. This permitted exercise variation to be achieved during the study.

Stimuli

Participants selected 10 of their favorite songs for use in the study. Once the songs were selected they were tempo mapped and edited to last exactly 2 mins each. 4 percussive metronome clicks were added at the appropriate bpm to the beginning of every track to give a clear and stable auditory cue to start playing. Four percussion sounds (Hi-Hat, Woodblock, Snare and Tom) were mapped to specific digital drum pads and were triggered by hitting the digital drum pads with hands or other items such as spoons and exercise balls.

Procedure

Participants took part in 3 x 30 minute music making sessions per week (15 sessions in all spread over a 5 week intervention phase), during which they entrained to the beat of 10 self-selected songs. Via the App, patients were visually cued to perform 4 basic physical movements: bimanual tapping on the proximal drum pads, bimanual forward and backward movements, using proximal and distal pads or diagonal reach between proximal and distal pads (in both directions) using the affected limb only. Each exercise ensured that the individual was working on specific goals at their maximum forward reach for sustained periods of time.

RESULTS

Time on task (TOT) was tracked via the App for each participant (Figure 2). All participants were tracked undertaking self-managed practice for at least 5 hours when subtracting the total researcher led exercise time. P1 and P2 continued to use the devices post study while P3 decided not to carry on due to space limitations within his living space.

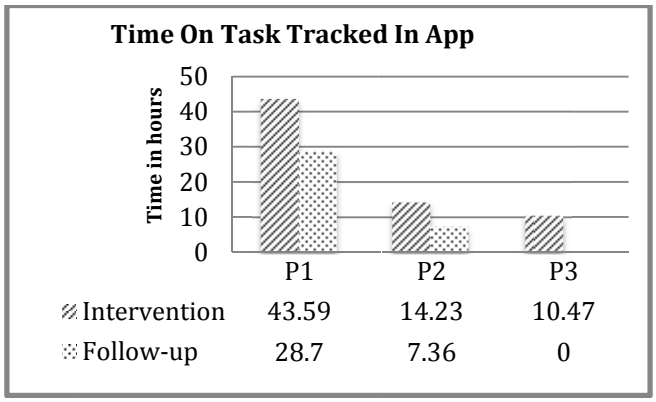

Figure 2: Participants time on task as tracked in the App showing the totals during the intervention (5 weeks period) and at three month follow-up (full 3 months post intervention).

All participants reported high levels of motivation and enjoyment when playing the digital drum pads as evidenced in the daily diaries. They all rated that the App was very easy to use and stated that it was not quite so easy to play the drum pads with the diagonal exercises (as opposed to forward) considered more difficult. Qualitative[1] feedback from the participants indicated that for future iterations of the digital drum pads, attention should be paid to the material properties with a suggestion of rubber vs hard plastic surface. All participants stated that they would not have enjoyed entraining to songs they had not chosen; P2 said "I want to choose my own music, I enjoy it, yes! If you was to choose other music I won't enjoy it..." Additionally, a greater selection of songs was requested by two participants.

All physical impairment measures improved during the intervention phase and were retained or improved further during the post intervention phase. There was a significant difference in measurement of arms length reach test for P1 using their affected right arm; conditions $t(18) = 2.40$ $p = .028$. P1 and P2 had significant increases in both shoulder flexion (lifting arm up) and wrist extension (lifting hand up). The majority of physical impairment measures taken at three months post intervention stayed above pre-intervention levels showing that the participants retained many of their gains by keeping up a regular exercise regime

[1] Find summaries of qualitative feedback at our online data source: httdp://doc.gold.ac.uk/~pkirk009/StrokeProject.htm

(approx. 40 mins per week for P2 and approx. 2.5 hours per week for P1).

The semi-structured interviews corroborated the physical improvements and provided some evidence for transfer of physical improvements into tasks of daily living, with P1 reporting that he could put his socks on easier using both hands. He additionally stated that, "It's got my brain working. I can remember stuff", when talking about remembering song lyrics by tapping to the beat of songs and singing. P2 reported slight improvement in wrist movement and P3 reported finding dressing easier. The majority of psychological scores also improved post intervention with the largest gains evidenced with the stroke specific quality of life scale (subscales cover energy, upper extremity function, mood and personality to name a few).

Qualitative feedback from health experts emphasized the significance of stroke survivors engaging in regular physical exercise by playing the digital drum pads, given that many stroke survivors do not partake in any physiotherapy of their own volition post-discharge from hospital. Suggestions were made that future versions could include the ability to set individual goals (number of daily repetitions) for each participant who could then visualize their progress towards these goals via LED feedback embedded in the devices or similar. The neurologist also recommended the inclusion of vertical exercises in future design considerations (the current paradigm works on the horizontal plane only).

DISCUSSION

The feasibility study aimed to assess the use of DMIs as an aid for stroke rehabilitation in the home. There was some anecdotal evidence for a transfer of physical gains into tasks of daily living from qualitative analysis. The report from P1 that playing the digital drum pads helped with his ability to remember song lyrics by singing and tapping out the syllables of lyrics to self-selected songs on the DMIs illustrated a striking form of self-management that could well have facilitated further motor learning, as the sessions involved many hundreds of repetitions. The cognitive improvement is similar to the findings that listening to self-selected songs can have benefits to cognition in stroke survivors [19].

The finding that two of the three participants were still using the devices 3 months after the end of the study speaks to the motivating qualities of the approach. Despite this, the time on task was considerably reduced at follow up, reflecting the known difficulties in maintaining an exercise regime, especially once the novelty of a new approach is reduced. The relatively small selection of songs (n=10) may have limited the degree of engagement during the three months post study. Further, as participants do not currently have the ability to set targets or track progress, it is possibly harder to retain high levels of motivation. However, it is encouraging that despite a decrease in overall exercise time both participants have kept up regular physical rehabilitation that they would not otherwise be doing as well as retaining most physical gains. Nevertheless, P3 decided not to continue the exercises because the setup took up too much space in his home. This is an important finding and has caused a lower long-term engagement that should be considered for future designs.

We believe that working closely with health experts who may deploy the devices if they become available on the market, and stroke survivors who are the ultimate users, is an essential method for creating products that have long-term relevance. Extensive user testing prior to running a study is highly recommended and though not achieved fully in this study we believe our approach has much potential in laying a framework for a general approach to rapid prototyping for the health sector, and in particular home rehabilitation. If no staff are on hand to help undertake exercises the digital devices need to be very easy to use and deploy. As far as gaining good, rich, qualitative feedback, we recommend to screen more stringently for cognitive deficits in participants.

When working through the exercises with the researcher leading the session, participants were encouraged to work towards a maximum forward reach, with the researcher physically moving the blocks further away from the participants. This was not easy for participants to do on their own. Between sessions the blocks were left in a set position that encouraged a forward reach that was not too exerting for them. This is a barrier for achieving variation that is completely self-managed and as such, future systems should aim to permit easy variation so that participants who are not able to lift and move the digital drum pads around can still have enough variation in movement.

A recommended addition to the stroke exercise App is to embed short exercise videos to show participants clearly how to perform specific movements. This may be a good approach when participants have cognitive deficits. Additionally, the use of wearable devices to track limb trajectory such as Salazar et al [18] could be a useful approach. Of particular interest would be having the ability to let the participants know if they are performing the exercise appropriately (i.e. if ovecompensation is evident the App could warn participants by stopping the music).

The current feasibility study suggests that DMIs can provide a valuable tool for the self-management of rehabilitation, providing motivational aids for long-term exercise. By using song playlists the costs are arguably less than developing new games and the approach may be more suited to user preferences, providing the playlists can be updated to keep the activities novel and motivating alongside goal setting. As there are no prior studies we know of using DMIs in the home for self-management this appears to be an under researched area in rehabilitation. We believe the field of HCI has much more to offer in this regard.

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